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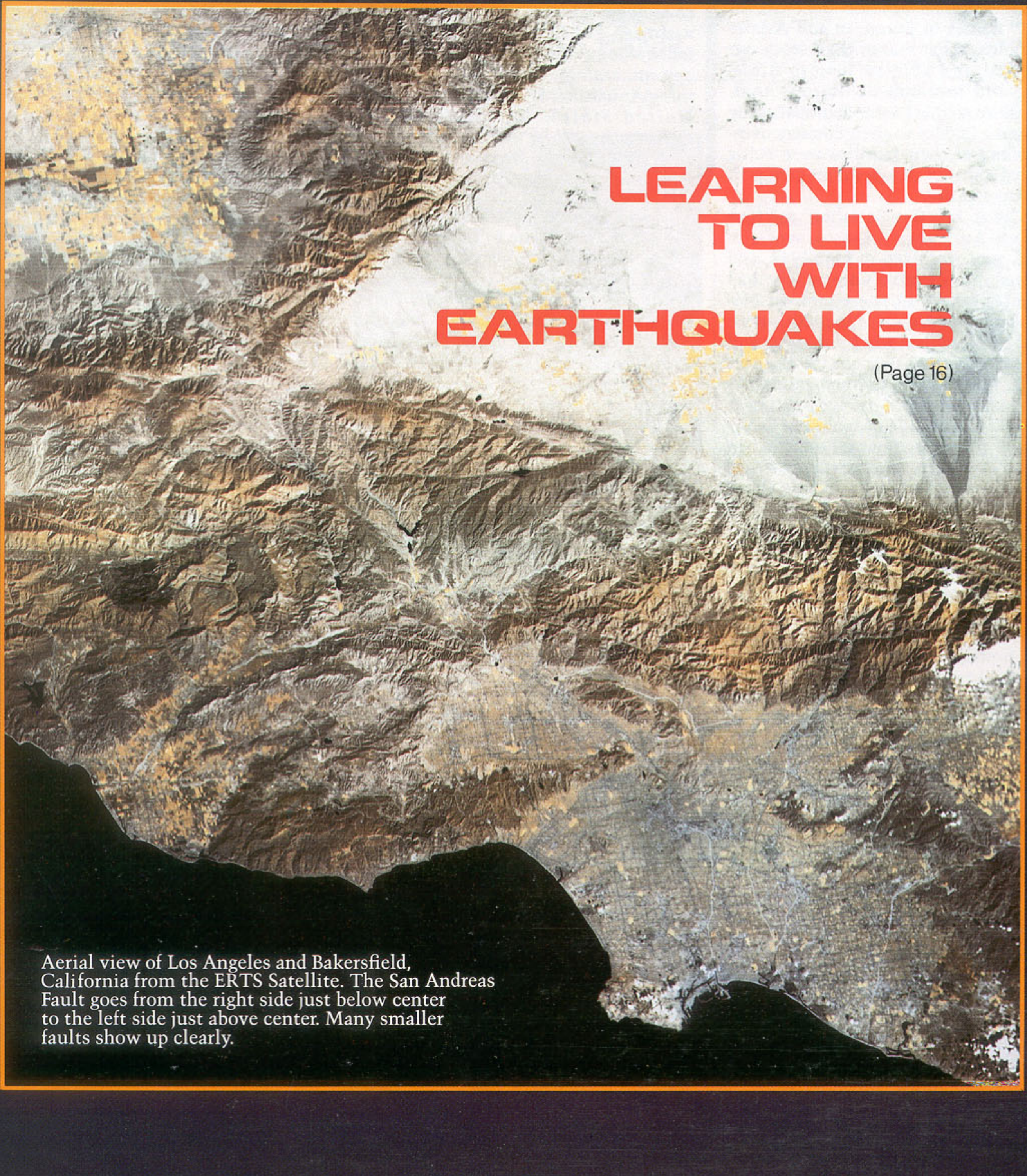


Aerial view of Los Angeles and Bakersfield, California from the ERTS Satellite. The San Andreas Fault goes from the right side just below center to the left side just above center. Many smaller faults show up clearly.

LEARNING TO LIVE WITH EARTHQUAKES

by PETER and KAREN WARD

Major damaging earthquakes will occur again in California. Scientists agree it is inevitable. Thousands of people will be killed and damage will be in the billions of dollars. But when? How can we evaluate this real but not necessarily imminent threat? What can we do to minimize the risk to ourselves, our families, our communities?

There are many threats to our lives — cancer, smoking, automobile accidents, to name a few. There are regional threats — tornadoes in the midwest, hurricanes in the southeast, and earthquakes in California. We have no choice but to accept risks as part of life. You can choose, however, to take precautions. You can buy insurance. You may reduce your exposure by giving up smoking, fastening seat-belts, or deciding where to live. You might choose to ignore the problems and live in happy oblivion. These are conscious choices that you can make both personally and in groups. You may be lucky and you may be unlucky. You certainly can improve your luck by developing a basic understanding of the problem and taking appropriate precautions.

The ground we live on seems so stable and yet earth scientists know that the continents have been deforming slowly for several billion years. The earth's surface is made up of approximately one dozen large plates nearly 40 miles thick that move relative to one another. Europe, for example, is moving eastward away from North America at approximately three quarters of an inch per year, and the Pacific Ocean is moving northwest relative to North America at a rate of more than two inches per year. In some areas under oceans the plates are growing and in other areas the edges of some plates are sinking into the interior of the earth. Most large earthquakes occur at the boundaries between the plates.

One such plate boundary slices through California along the San Andreas Fault. This fault is evident from the Gulf of California in northwestern Mexico, northward and east of Los Angeles, just west of San Francisco, and along the coast to Cape Mendocino in Northern California. The San Andreas Fault is really a zone sometimes miles wide consisting of nearly vertical cracks along which the land to the west is moving horizontally and northwest relative to the land on the east. On the average Los Angeles is moving about two inches closer to San Francisco every year or thirty-five miles closer every million years. The motion is typically not constant but occurs sporadically during earthquakes. During a larger than magnitude 8 earthquake, horizontal motion of tens of feet will typically occur within seconds along a 100 to 200 mile section of the fault. As the motion occurs, elastic energy is released, shaking the ground for hundreds of miles in all directions and causing damage. The intensity of the shaking typically dies off exponentially with distance from the fault.

Earthquake magnitude is a logarithmic measure of the amount of energy radiated from an earthquake. A magnitude 4 event is typically felt in a small area and a magnitude 6 event can cause serious damage near the fault. The energy radiated by a magnitude 7 event is 30 times that of a magnitude 6 event and 27,000 times that of a magnitude 4 event. The energy radiated by a magnitude 8 earthquake is nearly one million times that of a magnitude 4 event. In a given period of time, there are typically 10 times as many earthquakes of magnitude 7 as 8, 100 times as many events of magnitude 6 as 8, and 10,000 as many events of magnitude 4 as 8. Earthquakes of magnitude lower than 4 can not usually be felt. Events with magnitudes as low as 1 or 2 are routinely recorded and located by scientists to delineate where active faults

Highway overpasses damaged by the San Fernando, California, earthquake (magnitude 6.4) on February 9, 1971.

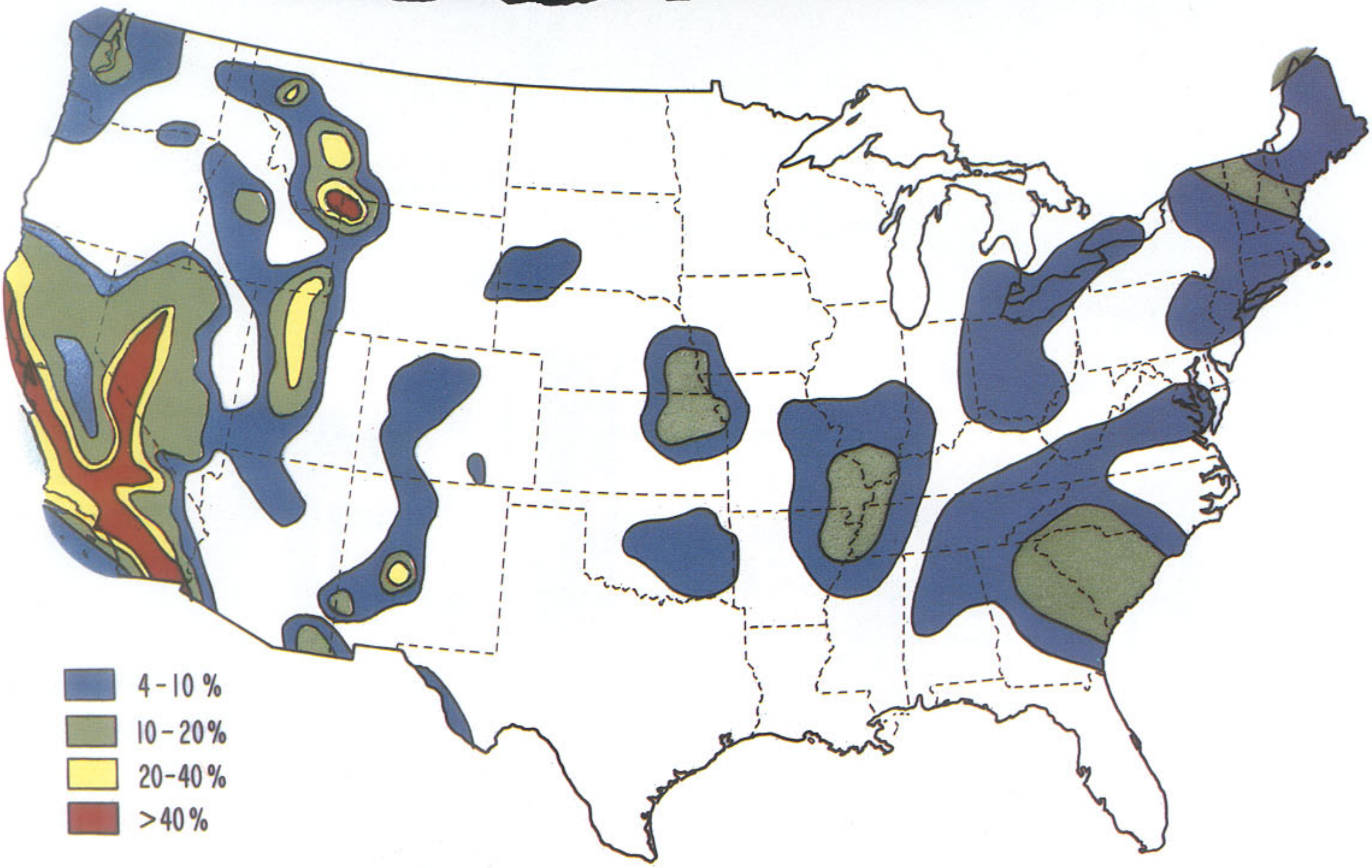
A view of San Francisco after the earthquake in 1906 (magnitude 8.3). While the front of the building on the right fell off, note how most of the buildings are standing. (Photo by G. K. Gilbert)

actually lie. Magnitude 6 earthquakes typically involve slippage along a few miles of a fault whereas magnitude 8 events involve slippage along a few hundred miles of a fault.

The last major earthquake of magnitude greater than 8 on the San Andreas Fault occurred in northern California in 1906. A similar event occurred in Southern California in 1857. Detailed geologic studies by Dr. Kerry Sieh, now at the California Institute of Technology, show that other large earthquakes along the San Andreas Fault in Southern California occurred approximately in the years 1745, 1470, 1245, 1190, 965, 860, 665, and 545 A.D. Thus major earthquakes recur along the fault in this area every 105 to 275 years. It is already 125 years since the last major event in Southern California! With this history and the longterm nature of the motion of plates, you can see why catastrophic earthquakes are inevitable in California.

The largest earthquakes in California will most likely be on the San Andreas Fault. There are many other faults in California and throughout the United States where smaller but very damaging earthquakes will occur. These smaller faults reflect the fact that the plate boundary is not a simple crack but often a complex zone of faults over a hundred miles wide. Some faults reflect primarily local stresses within the plates. In Southern California, for example, there are over 100 faults that scientists believe have slipped during earthquakes within the last 500,000 years and are likely to slip again in the future. Since many of these faults pass through very densely populated areas, the potential for damage is significant even from an earthquake of magnitude 6½. The 1971 San Fernando earthquake is a good example of such an event.

By studying the magnitude, location, and number of historic earthquakes and the rate at which seismic energy is dissipated with distance, we can designate where the regions are with the highest



risk of earthquake damage. While earthquakes have occurred in all states, they are more likely in certain areas. The enclosed national map shows the maximum likely ground motion expected in the next fifty years. Note the extremely high values in California, the high values in parts of the west, and the moderate values in parts of the Eastern United states. More detailed maps can be made of potential levels of shaking, for example, as shown for the Los Angeles region. This map is calculated based on the expected ground shaking from six possible earthquakes coupled with knowledge of the local geology and ground water conditions. Even these maps have been refined to include more detailed geologic information. It would be possible with sufficient new data to predict the levels of shaking in different parts of each town.

Damage during an earthquake is caused by two fundamental processes — ground shaking over a large region and surface faulting typically in a narrow zone. These processes may in turn trigger landslides, ground failure, seismic sea waves, and collapse of man-made structures. The shaking and faulting do not kill people. Faults do not swallow people. The real hazards to people are the secondary effects—landslides, building collapse, failure of dams, and more. The secondary effects can be predicted and avoided. Damage to property can be caused by shaking, for example by smashing all the dishes in a kitchen cabinet, but the greatest losses are likewise caused by secondary effects. With adequate time and money, we can build buildings and dams that will not fall down. We can deny development where landslides are likely. We can plan and build our communities to minimize the loss of life and property during earthquakes. There already exists adequate knowledge to know how to minimize earthquake hazards. The problem is that application of this knowledge involves difficult decisions and tradeoffs regarding how we spend limited funds, how much regulation of development is appropriate, and how imminent we perceive the threat to be.

For example, there are at least 10,000 brick buildings in Los Angeles County that were built prior to 1933, when strict new building code regulations were enacted as a result of a disastrous earthquake in Long Beach. Many of these buildings were built with lime mortar

The relative risk of damage from earthquake shaking throughout the United States. Numbers represent the maximum shaking expressed in percentage of the force of gravity likely to occur in fifty years.

that does not hold well during earthquakes and most are not reinforced adequately. In a major earthquake many will fall down and the loss of life in these buildings will be far higher than in most other structures. What should we do about it? This question has been discussed widely by local and state authorities. On the one hand, a major earthquake may not strike for another hundred years. If so, all of these buildings will have been replaced by the normal processes of decay and development. On the other hand, we could decide to close all of these buildings immediately, but what happens to the owners and the economy? The cost of reimbursing the owners or strengthening the buildings would be prohibitive. One proposal was to put a sign on each building stating the potential hazard as was done with the Capitol Building in Sacramento a few years ago. This solution would also have profound economic effects while not

necessarily saving lives. Who is to say that the threat is imminent enough to warrant any of these actions?

Another example is in San Francisco. Chinatown is predominantly built of these dangerous materials. Even if the money were available, what would be the cultural effects of rebuilding Chinatown? Where would the current residents go if a massive urban renewal campaign were started?

These questions raise tough economic and social issues whose solutions are typically worked out very slowly by the competing economic, political, social, and legal processes in our society.

There has been substantial improvement implementing concepts of earthquake hazard reduction in our communities. In the area of building design, for example, the Uniform Building Code has been strengthened and local codes introduced to require minimal earthquake resistance in structures. Structural engineers around the world have intensively studied the response of a structure to earthquakes and are continually developing new ideas about earthquake resistant design. Small changes in construction practices are being adopted that strengthen potential points of failure. Substantial expertise is being brought together to design tall buildings, bridges, nuclear reactors and other critical facilities. The cost of making a structure completely resistant to the maximum likely earthquake can be prohibitive. Thus decisions have to be made on each building regarding how resistant is resistant enough. One approach is to strengthen a building just enough that it will remain standing during an earthquake so that people are not killed, but recognize that structurally it may be damaged beyond repair and will have to be replaced after the earthquake. If the life of the building is 50 years and the next major earthquake does not occur for several decades, then this decision would be both prudent and cost effective.

Most Californians who live in wood frame dwellings, especially single story houses, are safe. These buildings typically respond well and do not collapse during an earthquake. Damage is most likely to involve chimneys, large windows, and falling objects within the house. Rooms up over a garage, for example, may fall because of inadequate support. A primary concern is to avoid fire by fastening hot water heaters and furnaces to the walls, and knowing where to shut off gas and electricity should a leak or short-circuit be caused by an earthquake. Residents of brick or cement buildings, multiple story buildings, etc., may wish to evaluate their risk. Several paperback books written for the public at large are available describing structural considerations with regard to earthquakes. You might consult your city or county building department. Many structural engineers are listed in the Yellow Pages who could provide professional advice.

Another area where earthquake hazard reduction techniques are being implemented is in town and regional planning. Our ability to predict the likely ground shaking within a community, allows regional planners to put parks in high hazard zones and hospitals and fire stations in low hazard zones. The damage from faulting can be virtually eliminated if either development is not allowed in fault zones or special types of construction are required in these areas. The Alquist-Priolo Act of 1972, requires the California Division of Mines and Geology to create official maps of the earthquake fault zones throughout California by 1985. Maps of the most populated regions have already been completed. Furthermore the Act requires that a seller or seller's agent of property within these fault zones must notify the prospective buyer of this fact. Detailed geologic studies are required before certain types of development can be done in these zones and special structural strengthening may be required to improve earthquake resistance. In the past many developments with hundreds of houses were built astride major fault zones. Now in some cases, developments have been built in similar areas but the roads and parks sit on top of the highest risk zones and houses nearby have been built with extra reinforcing to withstand shaking from earthquakes. In several urban areas realtors can show you maps delineating the fault zones.

Thus we can significantly reduce our exposure to earthquake hazards by proper community planning, construction, and knowledge of the potential problems. There has been significant improvement during the last decade in our awareness of these problems and implementation of appropriate mitigation measures. We still have a long way to go. Many homes lie within fault zones or on landslide-prone hills. Many existing buildings will not survive an earthquake. Some hospitals, police stations, fire houses, and even disaster offices are located in high hazard zones. It will take many decades before the problems are corrected by normal development. Thus if a major earthquake strikes soon in a populated part of California, and it could, damage will be high. Earthquakes of magnitude 6½ or

Maximum levels of shaking from earthquakes in Southern California assuming that major earthquakes occur along each of the six fault segments shown. The San Andreas Fault is the longest fault shown. Numbers refer to the modified Mercali damage scale where X means most masonry and frame structures destroyed with their foundations and VI means felt by everyone, some windows and dishes broken, some shelves and pictures fall from walls.